Coastal Benthic Optical Properties of Coral Environments: ROV/AUV Imaging

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LONG-TERM GOALS

The deconvolution, quantification, and interpretation of the various components of water-leaving radiance in shallow coastal waters are the long-term goals of the project.

OBJECTIVES

In this project, objectives include the development of instrumentation and models to measure and predict the contribution of bottom reflectance to upwelling radiance in coastal waters. An underlying objective, then, is the development of the methodologies required to remotely classify bottom types in varying water depths. Intrinsic in this effort are the quantification of the optical properties of the water column and the need to perform rigorous data calibration/validation while working toward optical closure, and to address the inherent problems of scale between *in situ* and remotely sensed data.

APPROACH

In the first funding year of the CoBOP project (FY96), transects over coral bottoms in the Dry Tortugas were laid out and mapped by divers and by the Fluorescence Imaging Laser Line Scanner (FILLS). Instrumentation aboard our Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) platforms were used to determine the color and intensity of bottom elements from different altitudes (Costello et al., 1997). The goal was to correct imagery for path radiance and attenuation, providing bottom albedo estimates for the dominant bottom types/features, to image bottom fluorescence, and to measure the vertical spectral structure of the upwelling and downwelling light fields. The analyses required rigorous validation, calibration, and modeling efforts. Simultaneously, effort was expended toward developing simple, relatively low-cost methods that could exploit gross bottom reflectance signatures to yield useful data.

In the 1998 funding year, a CoBOP field campaign was conducted from the Caribbean Marine Research Center (CMRC) located on Lee Stocking Island, Exuma Islands, Bahamas. Our responsibilities in the 1998 fieldwork were similar to those of the Dry Tortugas exercises with the

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14. ABSTRACT
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15. SUBJECT TERMS

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addition of extensive atmospheric measurements and the inclusion of sediment, grassbed, and mixed bottom types in addition to coral environments.

In the 1999 funding year, our approach was similar to our prior work with added effort toward rigorous instrument calibration and toward fruitful collaboration with other investigators.

Since the end of the CoBOP field campaigns, all work has been dedicated to data archiving and analysis.

WORK COMPLETED

General efforts:

- A method to quantify the spectral effects of bottom texture (i.e. sand waves) has been developed (Carder et al. submitted).

- A method which utilized color video taken from the OV-II AUV to calculate the percent live sea-bottom cover (Renadette et. al. 1997, 1998; Hou et. al. 1999) has been extended to multi-spectral imagery (Hou et al. submitted, Farmer et al, submitted).

- A method developed to model and utilize downwelling irradiance spectra affected by wave focusing (Costello et. al. 1998a) has been extended to include the upwelling radiance light field and provide for the calculation of reflectance as a function of depth (Costello et. al. 1998b) has been extended to include bottom albedos and water-leaving radiance (Costello and Carder, submitted).

- An analytical model was developed to predict the effect of internally reflected light over shallow,"patchy" bottoms (Costello and Carder, 1999).

Summary of CoBOP field efforts

- over 2,000 Hyperspectral (512-channel) downwelling irradiance and upwelling radiance spectra were acquired during 100+ vertical profiles performed using the ROSEBUD ROV over sand, seagreass, and corals.

- 6-channel, intensified bottom-albedo-video, NTSC-color-video bottom imagery, and a suite of IOP measurements were also obtained during each ROV deployment during each year.

- nearly 200 JSD drop-package casts were performed from the R/V Suncoaster and the R/V Subchaser. The JSD recorded CTD, ac-9, 0.2 micron-filtered ac-9, 488-nm attenuation, 830 nm backscatter, 6-channel HS-6 backscatter, Flashpak CDOM fluorescence, and chlorophyll fluorescence.

- Sea surface Rrs, filter pad (pigment, detrital, and CDOM) absorption and fluorometric chlorophyll were obtained at 118 stations.

- Color video bottom imagery was obtained during mapping transects in all field campaigns using the R/V Subchaser stern-mounted bottom camera. The imagery is overlaid with GPS position and

time. The Subchaser ship computer simultaneously logs water depth and surface temperature, boat speed and heading, and data from the boat meteorological instrumentation. The data are being input into a GIS data base (ArcView V3.1) for integration with data from other investigators.

- land-based atmospheric data were obtained (Reagan solar transmissometer, Licor, Micro-tops) daily as well as frequent ship-based R_{rs} measurements in support of the FILLS sensor flying aboard the AN-2 aircraft (C. Davis, NRL Washington).

RESULTS

- Water-Raman scattering and chlorophyll a fluorescence are extremely significant components of the upwelling light field at depths > 2 m and wavelengths > 520 nm over coraline environments and cannot be ignored in evaluating bottom-reflected (actively or passively) radiance.

- Solar-stimulated fluorescence at 685 nm from sediments due to benthic diatoms is ubiquitous on the Florida shelf, off the Florida Keys, and around Lee Stocking Island, Bahamas in sufficient intensity to allow the acquisition of narrow-band fluorescence bottom imagery (intensified video) from depths of 7 m to > 20 m.

- Animals (e.g. sponges) and man-made objects are readily apparent by their dark contrast with the bright, red, bottom fluorescence from benthic diatoms, coral symbionts, and macrophytes.

- Range to various components in an image greatly affects the 685-fluorescence signal since the e-folding depth through water is 2.5 m. Correction for range is critical for image interpretation (see Carder and Costello: N00014-96-1-5013).

- Wave focusing has a very significant spectral impact on the instantaneous downwelling light field on clear days providing red-rich irradiance in focal zones and blue-rich irradiance in divergence zones. Coral and vegetation fluorescence are spectrally and temporally dependent on the incident light field, and fluorescence "spill-over" may occur when photosynthetic reaction centers are full during wave focusing events but perhaps not for steady-state conditions providing the same time-averaged photon quality and quantity. Field measurements of IOPs and AOPs have allowed spectral model closure calculations to simulate the instantaneous spectral light field measurements. Increases in aerosols decrease these fluctuations due to wave focusing, stabilizing the light field (Costello et. al., 1998a). In clear, shallow coastal waters, upwelling radiance can be significantly affected by bottom reflection of focused downwelling irradiance (Costello et. al., 1998b).

- High-contrast, "patchy" bottoms in shallow waters can produce an increase in downwelling irradiance of up to 20% due to internal reflection of light beyond the critical angle (~48°) from bright sandy regions. Furthermore, the increased irradiance changes as a function of sensor depth convolved with the water column depth and the horizontal distance to contrasting "patches" (Costello and Carder, 1999). This large an effect indicates models assuming homogeneity in horizontal lightfields must be applied judiciously.

- Adjacency effects can cause a significant overestimate of bottom albedo as determined by in-water or air- or space-borne sensors (Hou et al. submitted, Farmer et al. submitted).

- Bottom texture (i.e. sandwaves) can spectrally alter upwelling radiance as a function of sun angle due to the spectral difference between diffuse and collimnated solar illumination (Carder et al. submitted).

IMPACT/APPLICATIONS

In our analysis of our hyperspectral light profile data sets, it soon became apparent that wave focusing and Raman scattering introduced significant complexity to models of the submarine light field. Moreover, modeling efforts toward addressing the complexities using Smith and Baker's (1981) water absorption numbers were generally fruitless. Use of Pope and Fry (1997) numbers, modeled skylight and sunlight fields (Gregg and Carder, 1990) and focus/defocus of the sunlight contribution provided modeled light fields consistent with measurements. Fluorescence and primary production models need to consider the nonlinear aspects of this light field versus traditional time-averaged methods.

Variations in the 685 nm fluorescence yields, suggested by our observations, ranged from high for hard-bodied coral, medium for branching coral, to low for benthic diatoms. These differences suggest possible automatic classification schemes if adequate range information is available. Certainly, non-vegetative bottom features such as animals and man-made objects are sharply discernible when viewed at 685 nm, and path radiance due to backscattering does not reduce image contrast for fluorescence-dominated scenes.

Aircraft and space sensor calibrations change with vibration, temperature, and time. Recalibraton is critical since a small change in calibration can introduce large errors. For example, the atmosphere contributes 90% (or more) of the radiance received at a space-borne sensor. Just a 2% shift in calibration would, then, result in a 20% error in the calculated water-leaving radiance. Reinersman et al. (1998) provide a vicarious method to re-calibrate a sensor that simply depends on finding small, compact clouds in a scene.

TRANSITIONS

The hyperspectral data acquired during this project has aided other projects (see RELATED PROJECTS section) in efforts toward the development and validation of algorithms for remote sensing of water constituents and bathymetry in coastal waters. In addition, the CoBOP-generated data base has been shared in the following cases.

CoBOP 2000 Data

Date: 1/15/01
Type: Corporate
Data: Multi-spectral bottom imagery secured in May, 2000 at various sites around LSI and Xybion 301 camera performance specifications
To: Charles Mazel, PSI Corp
From: David Costello, Carder Group, USF

Date: 3/1/01
Type: Inter-University
Data: in-water3-dimensional topographic and albedo of mine-simulants at LSI (ROBOT data) acquired in June 2001.

To: James Jalbert, Advanced Marine Systems, FAU
From: David Costello, Carder Group, USF

Date: 5/1/01
Type: Inter-University
Data: in-water IOP (a, b, bb) Ed Lu Rrs by drop package, Adderly Cut, CoBOP2000
To: Ken Voss, Univ Miami
From: Jim Ivey, Carder Group, USF

Date: 6/1/01
Type: Inter-university
Data: bathymetry map outside Adderly Cut, Exuma, CoBOP 2000
To: Pam Reid, Univ. Miami
From: Weilin Hou, Carder Group, USF

Date: 6/1/01
Type: Intra-group
Data: backscattering from in-water drop packages, offshore station, CoBOP 2000
To: Cheng-Chien Liu, Carder Group, USF
From: Jim Ivey, Carder Group, USF

Date: 6/15/01
Type: Intra-group
Data: hyperspectral (340-700nm) bottom albedo of sand/coral bottom NW of Adderly Cut, Exumas, secured 5/30/00.
To: David English, Carder Group, USF
From: David Costello, Carder Group, USF

Date: 6/15/01
Type: Intra-group
Data: hyperspectral (340-700nm) Ed and Lu from ROV BCAP for seagrass, sand and coral bottoms for modeling in-water IOPs and path radiance, taken near Adderly Cut, Rainbow Garden, and offshore station
To: Zhongping Lee, Carder Group, USF
From: David Costello, Carder Group, USF

Date: 6/15/01
Type: Intra-group
Data: typical hyperspectral (340-700nm) albedos for seagrass, sand and coral bottoms for utilization in heat budget modeling, secured at various times and sites (near shore)
To: Hari Warrior, Carder Group, USF
From: David Costello, Carder Group, USF

Date: 7/15/01
Type: Intra-group
Data: ROV BCAP data hyperspectral (340-700nm) and Xybion images for seagrass, sand and coral bottoms for utilization in albedo measurements (Rainbow Gardens, Adderly Cut and Horseshoe Reef)

To: Andrew Farmer, Center of Ocean Technology, USF
From: David Costello, Carder Group, USF

Date: 9/26/01
Type: Inter-University/WOOD database
Data: 2000 CoBOP ap,ad,ag,rrs, and chl in WOOD format (SEABASS), all stations
To: Jeffrey Smart, Johns Hopkins University – Applied Physics Lab
From: Weilin Hou, Carder Group, USF

CoBOP 1999 Data

Date: 5/1/01
Type: Inter-University
Data: Rrs, in-water bottle samples from of 5/27 to 6/1/99, CoBOP 1999
To: Anthony M. Filippi , Univ. South California
From: David English, Carder Group, USF

Date: 9/26/01
Type: Inter-University/WOOD database
Data: 1999 CoBOP ap,ad,ag,rrs, and chl in WOOD format (SEABASS), all stations
To: Jeffrey Smart, Johns Hopkins University – Applied Physics Lab
From: Weilin Hou, Carder Group, USF

Date: 4/1/00
Type: Inter-University
Data: 1999 CoBOP BCAP Xybion video for video mosaic testing
To: Zhigang Zhu, Univ. Massachusetts, Dept. Computer Sci.
From: Weilin Hou, Carder Group, USF

CoBOP 1998 Data

Date: 5/1/99
Type: Corporate /SEABASS database
Data: 1998 CoBOP ap,ad,ag,rrs, and chl in SEABASS
To: Jeremy Werdell, SeaWiFS, SIMBIOS Projects / NASA Goddard Space Flight Center
From: Jennifer Patch, Carder Group, USF

Date: 9/26/01
Type: Inter-University/WOOD database
Data: 1998 CoBOP ap,ad,ag,rrs, and chl in WOOD format (SEABASS)
To: Jeffrey Smart, Johns Hopkins University – Applied Physics Lab
From: Weilin Hou, Carder Group, USF

RELATED PROJECTS

As part of the CoBOP Directed Research Initiative, this project is synergistic with numerous other CoBOP investigations and several multi-discipline investigations are underway. This project also

provides significant data to and benefits from important instrumentation developed under "Optical Variability and Bottom Classification in Turbid Water" (ONR CODE 3220M).

Other collaborative projects:

ONR - *An AUV-based investigation of the role of nutrient variability in the predictive modeling of physical process in the littoral ocean*. PIs - K.A. Fanning and J.J. Walsh (USF).

ONR - *A simulation analysis of the time-dependent roles of phytoplankton and CDOM in effecting the 3-dimensional structure of inherent optical properties on the West Florida shelf*. PI - J.J.Walsh (USF)

ONR - *A Multi-Disciplinary Investigation of the Nature and Predictability of Sediment Resuspension in Shallow Water: Its Effect on Water Column and bottom Optical Properties*. PIs - A.C. Hine, D.P. Howd, D. Mallinson, D. Naar (USF), D. Wilson (USGS)

NRL - *Hyperspectral Modeling of Harmful Algal Blooms on the West Florida Shelf*. PI - W. P. Bissett (Florida Environmental Research Institute)

NASA Project - *Hyperspectral characterization of gelbstoff for application to remote sensing of carbon cycling in coastal regions*. PIs - P.Coble and C.Castillo (USF)

NASA (EOS) - *High spectral resolution MODIS algorithms for ocean chlorophyll in case II waters*. PI - K. Carder

NOAA - *Ocean Color Algorithm Evaluation for Remote Sensing of Coastal and Estuarine Waters*. PIs - R. Stumpf, P.Testor, J.Pennock, C.Tomas, R. Arnone, and K.Carder

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